

REVIEW ARTICLE

Barnacle culture: background, potential and challenges

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Abstract

There are approximately a dozen species of commercially interesting barnacles worldwide, some of which have been cultured on a semi-industrial scale. These species are listed and information is provided with regard to geographical distribution, landings and prices. Traditionally, 'goose' barnacles (four species) are considered to be the most important for consumption. World production already stands at 500 tonnes year⁻¹, but this species has not been cultured to date. Some 'acorn' barnacles are also consumed (seven species), with harvest levels per species that do not exceed 200 tonnes year⁻¹ and selling prices that can reach US\$17/kg. 'Acorn' barnacle culture on a world scale is still developing. Nevertheless, production has occurred on a semi-industrial scale; specifically, spat have been collected from the wild and grown in suspended systems. Farming trials have focused on two species of acorn barnacles: *Austromegabalanus psittacus* (Molina 1782) 'picoroco' in Chile and *Megabalanus azoricus* (Pilsbry 1916) 'craca' in Portugal. The large-scale production of these crustaceans will depend on the optimization of spat collection from the wild and/or the parallel development of mass production technologies for larvae (hatcheries). In addition, further development will be achieved by opening up new markets for commercialization.

Keywords: acorn barnacles, diversification, Chile, Azores

Introduction

Edible barnacles can be morphologically classified into two groups: lepadomorphs, commonly referred

to as 'stalked barnacles' or 'goose barnacles', and balanomorphs, called 'acorn barnacles', 'giant barnacles', 'picorocos', 'cracas', 'clacas' or 'fujit subos'.

Lepadomorphs are characterized by a fleshy peduncle, used for attachment to hard substrates (Barnes 1996), with significantly high fisheries exploitation for the Iberian market (Molares & Freire 2003).

Balanomorphs are generally exploited by small-scale fisheries, and recently, efforts have been made to develop artificial production technologies in both suspended culture systems and land-based tanks (López, López, González & Arriagada 2005; López 2008).

'Goose' and 'acorn' barnacles are sessile and gregarious, and one of the most abundant benthic species in the intertidal and subtidal zones. Their body is formed by a chitinous exoskeleton and calcareous plates. Species can be differentiated according to the dimensions and characteristics of these plates, with at least 900 species identified to date (Foster & Buckridge 1987; Schram & Høeg 1995). They are simultaneous hermaphrodites, with cross fertilization between adjacent individuals (Anderson 1994). During larval development, there are several planktonic larval stages that culminate in a competent larva, *cypris*, that attaches definitively to a substrate, before metamorphosis (Anderson 1994). 'Goose' and 'acorn' barnacles are omnivores that filter particles suspended in the water column, using the rhythmic movement of a group of six pairs of biramous cirri (Anderson & Southward 1987).

This paper provides the first compilation of commercially important barnacles worldwide and evaluates the current state of aquaculture for this group. The technological and economic potential of these organisms is highlighted, in the context of diversification in world aquaculture.

Commercially valuable barnacles

Lepadomorph barnacles ('goose barnacles' or 'stalked barnacles')

There are four commercially important species belonging to the *Pollicipes* and *Capitulum* genera

(Table 1). Within the *Pollicipes* genus, three species are harvested: *Pollicipes pollicipes* (Leach 1817), present on the Atlantic coast (Spain, Portugal, France and Morocco); *Pollicipes polymerus* (Sowerby 1833), on the Pacific coast of Canada and the USA; and *Pollicipes elegans* (Lesson 1830), endemic to the Pacific,

Table 1 Commercially viable barnacles on a world scale

	Scientific name	Common name	Geographic Distribution	Price	Consumption forms	Additional information
'Goose barnacles'	<i>Pollicipes pollicipes</i>	'Spanish goose barnacle'	Spain, Portugal, France, Morocco	€15–€25/kg	Fresh	Fishing is carried out by fishermen's unions, known as 'perceberos'. They extract on average 300–500 tonnes year ⁻¹ . Commercial size fluctuates between 7 and 10 cm height
	<i>Pollicipes polymerus</i>	'Canadian goose barnacle'	Canada, USA	€10–€15/kg	Fresh	Similar to the 'Spanish goose barnacle'. It is commercialized on the Iberian market
	<i>Pollicipes elegans</i>	'Pacific goose barnacle'	Mexico, Ecuador, Perú	€10–€15/kg	Fresh	Similar to the 'Spanish goose barnacle'. It is commercialized on the Iberian market and in Perú. Average extraction is 10 tonnes year ⁻¹
	<i>Capitulum mitella</i>	'Kamenote' or 'Japanese goose barnacle'	Japan	NA	Fresh	Consumption localized in southern Japan (Wakayama-Ken)
'Acorn barnacles'	<i>Austromegabalanus psittacus</i> (*)	'Picoroco'	Perú, Chile, Argentina	US\$1.7–US\$17/kg	Fresh, frozen, tinned	Small-scale, local extraction averages 200 tonnes year ⁻¹
	<i>Balanus nubilus</i>	'Giant barnacle'	Alaska, Canada, USA	NA	Fresh	Local consumption
	<i>Balanus rostratus</i>	'Mine fujit subo'	Russia, Japan	US\$12–US\$16/kg	Fresh, tempure, soup flavouring	Extraction in polluted coastal areas. Distribution restricted to certain coastal areas
	<i>Megabalanus rosa</i>	'Aka fujit subo'	Japan	NA	Fresh	Extraction in polluted coastal areas. Distribution restricted to certain coastal areas
	<i>Tetraclita japonica</i>	'Kuro fujit subo'	Japan	NA	Fresh	Extraction in polluted coastal areas. Distribution restricted to certain coastal zones
	<i>Megabalanus azoricus</i> (*)	'Craca'	Azores Islands (Portugal)	€2.5–€5/kg	Fresh	Typical product of the local traditional gastronomy
	<i>Megabalanus tintinnabulum</i>	'Claca'	Entire tropical zone of the Atlantic and Indian Oceans. Canary Islands (Spain)	NA	Fresh	Typical product of the local traditional gastronomy

Scientific and common names, in addition to details of geographic distribution, prices, consumption forms and other antecedents relative to their use.

(*) Cultures in progress at a pilot or a semi-industrial level.

Sources: Girard (1982); Bernard (1988); Lauzier (1999a, b); Jamieson and Levings (2001); Lessard, Osborne, Lauzier, Jamieson and Harbo (2002); Molares and Freire (2003); Castro (2004); Borja, Muxika and Bald (2006); Lotaçor (2006); López, López and González (2007); SERNAPESCA (1998–2008); Jacinto, Cruz, Silva and Castro (2009); G. Otohe (pers. comm.).

NA, no data available.

from Mexico to Chile. *P. pollicipes* is mainly consumed on the Iberian market, particularly Spain (Freire & García-Allut 2000; Molares & Freire 2003; Bald, Borja & Muxika 2006; Borja, Muxika & Bald 2006; Borja, Liria, Muxika & Bald 2006). The 'Spanish goose barnacle', 'percebe' (*P. pollicipes*), is caught principally in Galicia, in the wave zones of exposed coasts, and can reach up to 10 cm in height. Only the fleshy peduncle, used to adhere to the substrate, is consumed fresh. Over the past few years, 300–500 tonnes year⁻¹ were harvested to supply local markets, where the demand is considerable. Prices fluctuate between €19 and €31/kg. and, depending on the quality, can reach values over €80/kg (Molares & Freire 2003). Given the high demand for this product, together with supply problems resulting from the overexploitation of natural banks and pollution in the harvest zones, the market is supplemented by other species (e.g. *P. polymerus* and *P. elegans*) that are smaller (< 5 cm) and less expensive (€10–€15/kg) (Bald *et al.* 2006).

Among the genus *Capitulum*, *C. mitella* (Linnaeus 1758), 'kamenote' is the only species that is harvested. It is a small barnacle (< 5 cm height) consumed on the southern coast of Japan (G. Otake, pers. comm.).

Balanomorph barnacles (acorn barnacles)

There are at least seven commercially significant balanomorph species from the *Austromegabalanus*, *Balanus*, *Megabalanus* and *Tetraclita* genera (Table 1). They are conical, surrounded by calcareous plates with a flat base and lack the peduncle, characteristic of the goose barnacles. The opercular aperture, from where the cirri and the penis emerge, can be completely closed off by the opercular plates, thus isolating individuals from the environment (Anderson 1981; Hunt & Alexander 1991). In this group, the adductor muscles of the opercular plates and the female gonad, located on the base of the animal, are consumed.

Austromegabalanus psittacus (Molina 1782) 'picoroco' is a giant barnacle, distributed in the Pacific Ocean, from southern Peru (Pacasmayo) to the Straits of Magellan, including the Juan Fernández archipelago and southern Argentina, on the Atlantic (López, López & González 2007). Specimens have also been recorded in New Zealand, transported passively as ballast water (Hosie & Ayhong 2008). This species inhabits rocky substrates in the subtidal zone, between 5 and 7 m, forming dense aggregates that can reach heights of up to 30 cm. They have the capacity to modify their base, according to the density at



Figure 1 Fishery landings of giant barnacle *Austromegabalanus psittacus*, 'picoroco' in Carelmapu, southern Chile (42°S). Photograph courtesy of S. Arriagada.

which individuals grow (López, López, Burgos, Arriagada & González 2007), and rapid growth (López, Espinoza, López & Santibáñez 2008), both of which favour aquaculture practices. This species has been used in physiological research work due to the size of its muscular fibres (Bacigalupo, Luxoro, Riseti & Vergara 1979; Hidalgo, Luxoro & Rojas 1979). It is an economically important species in Chile, where it is exploited on a small scale by artisanal fishers (Fig. 1), with harvests that fluctuate between 200 and 600 tonnes year⁻¹. It is preferentially consumed fresh, and attains prices of between US\$1.5 and US\$1.7/kg on the domestic market. However, it can also be frozen (US\$10/kg) and canned (US\$12/kg). Exports of between 5 and 10 tonnes year⁻¹ are destined principally for Asia.

Another giant barnacle, *Balanus nubilus* (Darwin, 1854) (10–15 cm height), is found along the Pacific coast from Alaska to southern USA. It is only consumed by indigenous populations on the NE coast (Morris, Abbott & Haderlie 1980). It has also been used in physiological studies on nerve impulses in muscle fibres (Hoyle 1987).

Three 'acorn' barnacle species are economically important on the Asian coast of the Pacific, particularly in Japan, where barnacles are commonly known as 'fujit subo'. The main species is *Balanus rostratus* (Hoek 1833), 'mine fujit subo', which does not exceed a height of 5 cm. It is harvested in the northern part of the country (Aomori), and consumed fresh, as tempura (similar to scaloppini) and as flavouring in soups. Average production ranges between 6 and 7 tonnes year⁻¹ and is concentrated during the spring–summer period, when prices reach around US\$15–US\$17/kg. In central–southern Japan, other species are consumed: *Megabalanus rosa* (Pilsbry

1916), 'aka fujit-subo' and *Tetraclita japonica* (Pilsbry, 1916) 'kuro fujit-subo'. These species are smaller than *B. rostratus*, exploitation is irregular, landings are marginal and prices are lower than their northern counterpart (G. Otake, pers. comm.).

Finally, in the northeastern Atlantic, particularly in some of the Macaronesia islands (Azores, Madeira and Canaries), 'acorn' barnacles are a highly appreciated food source. It remains to be determined whether there are two distinct species, or only a single species complex, throughout the region (Hawkins, Côrte-Real, Pannacciulli, Weber & Bishop 2000; Wirtz, Araújo & Southward 2006).

In the Azores, *Megabalanus azoricus* (Pilsbry 1916), locally known as 'craca', is abundant below the low tide mark of exposed rocky shores and is subject to intensive harvesting (Santos, Hawkins, Monteiro, Alves & Isidro 1995; Southward 1998; Regala 1999). According to landing statistics (Lotaçor 2006), extraction around the whole archipelago reaches, on average, 3–7 tonnes year⁻¹. However, this figure is highly unrepresentative of the true volumes, because much of the catch is not officially auctioned and is sold outside conventional markets. Commercial size is close to 1 cm carinorostral length, and prices as a fresh product fluctuate between €1.4 and €3.6/kg (data from 2002 to 2006 from Lotaçor 2006). Although no comprehensive study has been undertaken, it is believed that natural populations are threatened by the high collection levels in some areas of the archipelago (Regala 1999). In fact, the OSPAR convention (1996–2006) has included *M. azoricus* on its list of threatened species, requiring special attention.

In Madeira (Portugal) and the Canaries (Spain), *Megabalanus tintinnabulum* (Linnaeus 1758), 'claca', is harvested at very low levels. It is more widely distributed in the tropical zone of the Atlantic and Indian Oceans, and is only commercialized in the Canary Islands, where it is consumed fresh. No further information is available regarding extraction volumes and prices.

Barnacle aquaculture

To date, for 'goose barnacles', the only experimental culture trials undertaken have been aimed at spat collection for *P. pollicipes* in suspended systems along the Galician coast (Goldberg 1984), but the results were not encouraging. It appears that larval settlement only occurs on the peduncle of conspecifics, making the use of artificial substrates very difficult



Figure 2 Juvenile specimens of giant barnacle *Austromegabalanus psittacus*, 'picoroco', adhered to artificial collectors. Photograph courtesy of B. López.

and limiting the areas where spat collection can be carried out. Based on field studies and laboratory cultures, information has been gathered on the reproductive cycle and the larval development of this species (Molares, Tilves & Pascual 1994; Cruz & Hawkins 1998; Cruz & Araújo 1999).

For 'acorn barnacles,' results are more promising, particularly *A. psittacus* and *M. azoricus*. For 'picoroco' (*A. psittacus*) culture technologies have been developed in southern Chile (42°S), where, historically, extractive fisheries of this species have been undertaken. Efforts have concentrated on the design and production of artificial collectors for obtaining natural seed, as well as growth technologies for adults in suspended systems and land-based tanks. With regard to seed collection, the efficiency of different artificial substrates (PVC tubes and plates) (Fig. 2) has been tested at different depths and seasons of the year. Results show high recruitment levels on artificial substrates at depths of 4–6 m during spring and summer, with collection values that range between 0.02 and 0.07 individuals cm⁻², depending on the type of substrate. Recruitment density was consistently greater on PVC substrates than on other surfaces (Fig. 3). Nevertheless, recruitment occurs all year round.

Systems have been used for the 'fattening' phase, where subsequent growth of individuals signifies a 15-fold increase in biomass over a period of 18 months. The process can occur in the same substrate as larval settlement (cultch) (Fig. 4) and in systems where the settlement stages and growth occur in different substrates (cultchless). According to information obtained in 'cultch'-type systems, instantaneous growth rates decrease with age, with average values of 0.03 cm carinorostral length/day during the early

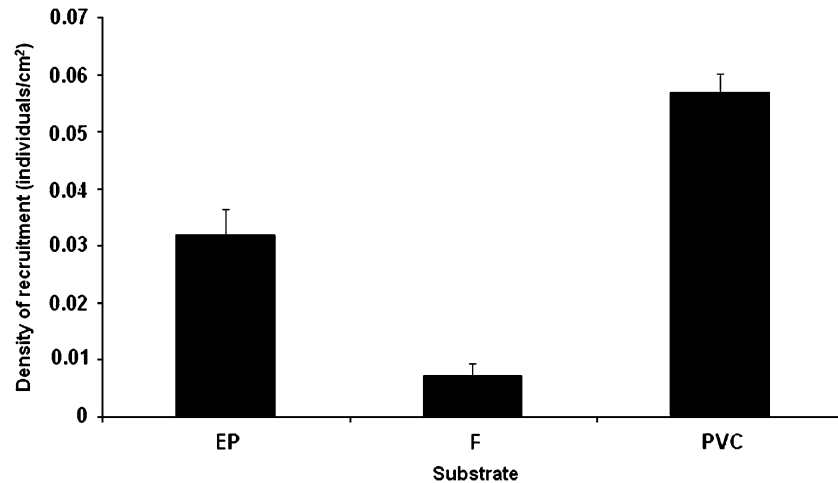


Figure 3 Average + 1SE of recruit density in artificial giant barnacle collectors *Austromegabalanus psittacus* 'picoroco' in southern Chile (Metri Bay, 41°36'S; 72°42'W). EP, expanded polystyrene; F, felt (bidín); PVC, polyvinyl chloride.



Figure 4 Commercial sized adult specimens of giant barnacle *Austromegabalanus psittacus*, 'picoroco' in Chile (average 3.5 cm opercular aperture) growing in suspended tubular systems (polyvinyl chloride). Photograph courtesy of B. López.



Figure 5 Aggregate of cultured giant barnacle *Austromegabalanus psittacus*, individuals. Photograph courtesy of B. López

months and 0.0005 cm carinorostral length/day after 18 months; the average commercial size for the Chilean market of 3.5 cm opercular length (density-independent growth measurement in barnacles), equivalent to > 10 cm height and 150 g total weight, can be reached in 18–24 months, with mortalities that do not exceed 20%; a suspended system, such as a 100 m long-line, can generate between 7 and 10 gross tonnes of product, with meat yield fluctuating between 15% and 20% (20–30 g per individual). Specimens generally grow in groups (Fig. 5) and studies in land-based tanks (Fig. 6) have verified the importance of water flow, as well as the quantity and the quality of food, in the development of industrial-scale cultures, given that the growth rates obtained have



Figure 6 Individuals of the giant barnacle *Austromegabalanus psittacus*, 'picoroco' growing in land-based tanks in southern Chile (Metri Bay, 41°36'S; 72°42'W). Photograph courtesy of B. López



Figure 7 *Megabalanus azoricus* 'craca' specimens adhered to artificial tubular collectors at a depth of 10 m. Photograph courtesy of C. Pham

been comparatively lower than those observed in suspended systems.

The commercial size and type of *A. psittacus* products depend on the market, Japan being the main potential market for the fresh-chilled product. Here, *A. psittacus* can be a periodic substitute for 'mine fujit subo' due to the similarities in the size and the seasonal harvest of the Japanese 'acorn barnacle'. The 'picoroco' can achieve the commercial size of 'mine fujit subo' in approximately 8 months. The price of the fresh product reaches US\$15–US\$17/kg. Markets such as the USA and Europe (Spain, France) are also potential destinations for frozen and canned products.

M. azoricus culture is currently undertaken in the Archipelagos of the Azores (Pham, Higgins, De Girolamo & Isidro 2008). Experiments on seed collection and growth have been carried out on artificial floating substrates such PVC tubes at depths of 9–12 m (Fig. 7). Recruitment occurred all year round, with a peak between July and October. Artificial substrates were rapidly colonized, with a final density, after 15 months, of 1109 individuals m^{-2} . Considering the growth rates observed over an 8-month period and the local commercial size (1 cm average carinorostral base length), the barnacles would be harvestable after a production cycle of approximately 24 months, with a

low mortality rate mainly due to the occurrence of predatory Stylochid flatworms. Although there are indications that there is a potential market for this product in Europe, further evaluation is required.

'Acorn' barnacle aquaculture: projections

In comparison with other crustaceans such as shrimp, king crab and lobsters, which are carnivorous, mobile and territorial and, thus, require production technologies that occupy large spaces, the 'acorn' barnacles are omnivorous, sessile, gregarious filter-feeders that can be cultured using simple, low-cost technologies, and their production is environmentally sustainable, given that they do not require exogenous feeding. However, an evaluation of carrying capacity according to local environmental conditions must be taken into account, to determine the impact of extensive culture on the landscape and ensure acceptance by the general public.

Seed can be obtained from the wild throughout most of the year, fecundity is high and they are characterized by early sexual maturity and rapid growth. Furthermore, they can tolerate high densities, without suffering negative effects (López *et al.* 2005, López, López, Burgos *et al.* 2007), and are highly resistant to manipulation and adverse environmental conditions (such as hypoxia or salinity), facilitating their live transport (López, Castro, González & Simpfendorfer 2003; López & López 2005).

The main challenges to be met by 'acorn' barnacle cultures are to ensure both a sufficient and a reliable quantity of seed. While production is limited, this challenge can be met with natural seed, both in the case of 'picoroco' and 'craca' (although, in the latter case, further research is required). Nevertheless, at higher production levels, it will be necessary to produce seed in hatcheries. Seed production will enable cultures to be independent of the spatial and temporal variability that affects seed collection in the natural environment.

Barnacle larvae production efforts in the laboratory date back to over 50 years ago (Knight-Jones 1953; Costlow & Bookhout 1958), and different records of methodologies and larvae culture conditions are available (Brown & Roughgarden 1985; Qiu & Qian 1999; Mishra, Kitamura & Tomoda 2001; Thiagarajan, Harder & Qian 2003). Similarly, energetic and behavioural aspects of the *cypris* have been studied (Keough & Downes 1982; Khandeparker, Anil & Raghukumar 2002; Thiagarajan, Harder, Qiu &

Qian 2003), in addition to inductor and inhibitor effects on larval settlement and metamorphosis (Gabbott & Larman 1987; Maki, Rittschof, Costlow & Mitchell 1988; Matsumura, Hills, Thomason, Thomason & Clare 2000; Dreanno, Kirby & Clare 2007; Tremblay, Bourget & Rittschof 2007; Qiu, Hung & Qian 2008). However, seed production in hatcheries results in increased production costs, only justifiable if developed in parallel with the opening up of international markets. Culture of the giant barnacle with seed obtained from the wild is economically viable for two processed products: canned and frozen meat, with annual profitability exceeding 10%. They can reach prices of up to US\$25/kg on the Japanese market, in periods when the demand is high (J.A. López, pers. comm.).

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